

Spacing Configuration Engineering Model of Two Adjacent Warships for Ship-to-air Missile Defense

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Abstract

During ship-to-air missile air defense operation, in order to prevent two adjacent warships detected by the azimuth searching of anti-ship missile homing radar at the same time, and study mutual protection of two ship-to-air missile systems aboard two adjacent warships, as well as point defense ship-to-air missile system protected by area defense ship-to-air missile system, this paper has established corresponding spacing configuration engineering models by analytical method, which provides real-time decision making for spacing configuration of the two adjacent warships for ship-to-air missile defense.

Keywords

Two Warships; Spacing Configuration; Ship-to-air Missile; Engineering Model

Introduction

The core of air defense disposition for ship-to-air missile systems during ship-to-air missile air defense operation is spacing configuration of two adjacent warships. In different circumstances, different spacing configuration models of the adjacent warships for decision making should be established.

Prior works have established nonlinear programming model of both spacing configuration of two adjacent warships (Jiayin Zhao etc, 2010), and formation configuration (Ansheng Tan etc, 2003) (Leiting Ma etc, 2000), as well have proposed fuzzy DEA evaluation method to evaluate formation configuration scheme (Hao Li etc, 2009). Computer simulation is essential for the above methods, however, due to the time consuming computation, the methods can't be used for real-time decision making for spacing configuration of the two adjacent warships for ship-to-air missile defense.

By means of analytical method characterized with simple calculation, this paper has established

configuration engineering models to prevent two adjacent warships detected by the azimuth searching of anti-ship missile homing radar at the same time, and mutual protection of two ship-to-air missile systems aboard the two adjacent warships, and point defense ship-to-air missile system protected by area defense ship-to-air missile system, which provides real-time decision making for spacing configuration of the two adjacent warships for ship-to-air missile defense.

Page Layout Configuration Engineering Model of Preventing Two Adjacent Warships Being Detected by the Azimuth Searching of Anti-ship Missile Homing Radar at the Same Time

In FIG. 1 and FIG. 2, when two adjacent warships (let G_{bq1} and G_{bq2}) are attacked by a anti-ship missile (let D_{bq1}), D_{bq1} usually flies towards a warship (assume G_{bq1}). Let O_{bq} be started working point of anti-ship missile homing radar, and D_{Lbq} be the homing radar range, and $|O_{bq}G_{bq1}| = D_{Lbq}$. It is assumed that D_{bbq} is the half width of search sector of the homing radar, and β_{bq} the homing radar azimuth angle, as well as the angle between $O_{bq}G_{bq1}$ straight line and $G_{bq1}G_{bq2}$ straight line, and $|G_{bq1}G_{bq2}| = L_{bq}$.

When $0^\circ < \alpha_{bq} \leq 90^\circ$

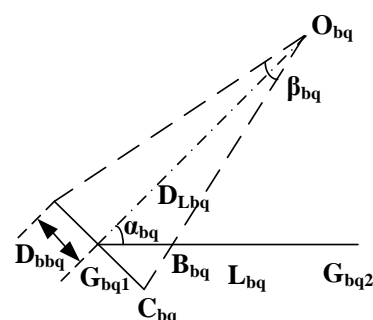


FIG. 1 SEARCH SECTOR OF ANTI-SHIP MISSILE HOMING RADAR WHEN $0^\circ < \alpha_{bq} \leq 90^\circ$

In FIG. 1, B_{bq} is the intersection point between $O_{bq}C_{bq}$ straight line and $G_{bq1}G_{bq2}$ straight line. At this time, when $L_{bq} \geq |B_{bq}G_{bq1}|$, the adjacent warships detected by the azimuth searching of the homing radar can be prevented at the same time.

$$D_{bbq} = D_{Lbq} \tan(\beta_{bq}/2) \quad (1)$$

Because $\frac{|B_{bq}G_{bq1}|}{\sin\left(\frac{\pi - \beta_{bq}}{2}\right)} = \frac{D_{bbq}}{\sin\left(\alpha_{bq} + \frac{\beta_{bq}}{2}\right)}$ (Baoxian Lv, 2013), it can be transformed by

$$|B_{bq}G_{bq1}| = \frac{D_{bbq} \cos\left(\frac{\beta_{bq}}{2}\right)}{\sin\left(\alpha_{bq} + \frac{\beta_{bq}}{2}\right)} \quad (2)$$

When $\alpha_{bq}=0^\circ$ or $\alpha_{bq}=180^\circ$

In FIG. 1, k_{sbq} is the homing radar range coefficient. At this time, when $L_{bq} \geq k_{sbq} D_{Lbq}$, the adjacent warships detected by the azimuth searching of the homing radar can be prevented at the same time. Let D_{Lbqmin} and D_{Lbqmax} be the minimum range and maximum range of the homing radar respectively, in addition, k_{sbq} can be calculated by

$$k_{sbq} = (D_{Lbqmax} - D_{Lbqmin}) / D_{Lbq} \quad (3)$$

When $90^\circ < \alpha_{bq} < 180^\circ$

In FIG. 2, when O_{bq} moves to the point (let O'), C_{bq} justly moves to the point (let C'). At this time, when $L_{bq} \geq |C'G_{bq1}|$, the adjacent warships detected by the azimuth searching of the homing radar can be prevented at the same time.

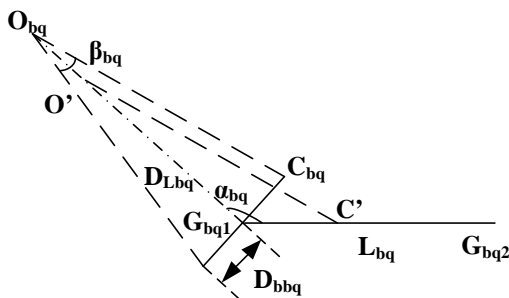


FIG. 2 SEARCH SECTOR OF ANTI-SHIP MISSILE HOMING RADAR WHEN $90^\circ < \alpha_{bq} < 180^\circ$

$$|O'C'| = \sqrt{D_{bbq}^2 + D_{Lbq}^2} \quad (4)$$

Because $\frac{|C'G_{bq1}|}{\sin\left(\frac{\beta_{bq}}{2}\right)} = \frac{|O'C'|}{\sin \alpha_{bq}}$, it can be transformed by

$$|C'G_{bq1}| = \frac{|O'C'|}{\sin \alpha_{bq}} \sin\left(\frac{\beta_{bq}}{2}\right) \quad (5)$$

When α_{bq} Value is Unknown

When α_{bq} value is unknown, L_{bq} is the maximum value of the calculated L_{bq} values when $\alpha_{bq}=0^\circ$ and $\alpha_{bq}=180^\circ$.

Configuration Engineering Model of Mutual Protection of Two Ship-to-air Missile Systems Aboard Two Adjacent Warships

Here, the configuration engineering model of mutual protection of two ship-to-air missile systems aboard the adjacent warships is proposed, under the assumption that the capabilities of the two missile systems are equal, and the firing frequency of the two missile systems for single target flying between the adjacent warships is no less than that of the single missile system aboard the single warship for the target by shortcut flight course at the single warship. Situation shown in FIG. 3, let ϕ_{bq} be the maximum route angle of the single missile system intercepting the target, and R_{bq} be the radius of horizontal projection of the fire zone of the single missile system, and the intersection points between the target threat direction and the horizontal projections of the fire zone of the two missile systems are B_{bq1} , B_{bq2} , D_{bq1} , D_{bq2} , and η_{bq} and U_{bq} are the angle and the intersection point between the target threat direction and $G_{bq1}G_{bq2}$ straight line respectively.

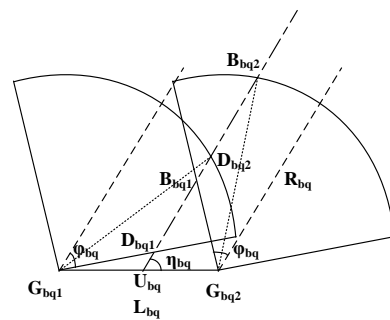


FIG. 3 SITUATION OF MUTUAL PROTECTION OF TWO SHIP-TO-AIR MISSILE SYSTEMS ABOARD TWO ADJACENT WARSHIPS

When η_{bq} Value is Known

At this time, when the firing frequency of the two missile systems for the target flying between the adjacent warships is equal to that of the single missile system aboard the single warship for the target by shortcut flight course, it can be defined by

$$|B_{bq1}B_{bq2}| + |D_{bq1}D_{bq2}| = R_{bq} \quad (6)$$

1) Solution Method for $|B_{bq1}B_{bq2}|$

$$|B_{bq1}B_{bq2}| = |U_{bq}B_{bq2}| - |U_{bq}B_{bq1}| \quad (7)$$

Because $\frac{|U_{bq}G_{bq2}|}{\sin \phi_{bq}} = \frac{|U_{bq}B_{bq1}|}{\sin(\pi - \eta_{bq} - \phi_{bq})}$, and

$|U_{bq}G_{bq2}| = L_{bq}/2$, $|U_{bq}B_{bq1}|$ can be calculated by

$$|U_{bq}B_{bq1}| = \left| \frac{L_{bq} \sin(\eta_{bq} + \phi_{bq})}{2 \sin \phi_{bq}} \right| \quad (8)$$

Because $\frac{|B_{bq2}G_{bq2}|}{\sin \eta_{bq}} = \frac{|U_{bq}G_{bq2}|}{\sin \angle U_{bq}B_{bq2}G_{bq2}}$, and

$|B_{bq2}G_{bq2}| = R_{bq}$, $\angle U_{bq}B_{bq2}G_{bq2}$ can be calculated by

$$\angle U_{bq}B_{bq2}G_{bq2} = \arcsin \left(\frac{L_{bq} \sin \eta_{bq}}{2R_{bq}} \right) \quad (9)$$

Because $\frac{|B_{bq2}G_{bq2}|}{\sin \eta_{bq}} = \frac{|U_{bq}B_{bq2}|}{\sin(\pi - \angle U_{bq}B_{bq2}G_{bq2} - \eta_{bq})}$,

$|U_{bq}B_{bq2}|$ can be calculated by

$$|U_{bq}B_{bq2}| = \left| \frac{R_{bq} \sin(\angle U_{bq}B_{bq2}G_{bq2} + \eta_{bq})}{\sin \eta_{bq}} \right| \quad (10)$$

2) Solution Method for $|D_{bq1}D_{bq2}|$

The solution method for $|D_{bq1}D_{bq2}|$ is the same as for $|B_{bq1}B_{bq2}|$.

3) Solution Method for spacing

L_{bq} value can be acquired based on Eq. (6) when the ϕ_{bq} , η_{bq} , R_{bq} values are known.

When η_{bq} Value is Unknown

At this time, L_{bq} value can be gained based on Eq. (6) when the η_{bq} value is varied within the given range $[0^\circ, 180^\circ]$. Afterwards, the maximum value value of L_{bq} value is taken (let $L_{bq\max2}$) as the final L_{bq} value.

Solution Method for R_{bq}

R_{bq} can be calculated by

$$R_{bq} = L_{fybq} + V_{fbq} t_{Ihl} \quad (11)$$

where t_{Ihl} is combat reaction time of the single missile system, L_{fybq} is maximum range of horizontal projection of the kill zone of the single missile system,

and V_{fbq} is the target speed.

Configuration Engineering Model of Point Defense Ship-to-air Missile System Being Protected by Area Defense Ship-to-air Missile System

When point defense ship-to-air missile system is protected by area defense ship-to-air missile system, the firing frequency of the point defense missile system for single target by shortcut flight course can be increased. It is assumed in this paper that the growth times of the firing frequency of the point defense missile system for the target is W_{bu} , and the configuration engineering model is proposed. Situation shown in FIG. 4, let G_{bu2} point be the point defense missile system's warship position, and G_{bu1} point be the area defense ship-to-air missile system's warship position, and $G_{bu1}X_{bu1}$ and $G_{bu2}X_{bu2}$ straight lines are the target threat directions, and η_{bu} is the angle between the target threat direction and $G_{bu1}G_{bu2}$ straight line, and ϕ_{bu1} , ϕ_{bu2} are the maximum route angle of the point defense missile system and the area defense missile system intercepting the target respectively, and D_{bu1} , D_{bu2} are the intersection points between $G_{bu2}X_{bu2}$ straight line and horizontal projection of the fire zone of the area defense missile system, and R_{bu1} , R_{bu2} are the radius of horizontal projection of the fire zone of the area defense missile system and point defense missile system respectively. The solution method for R_{bu1} and R_{bu2} are the same as for R_{bq} .

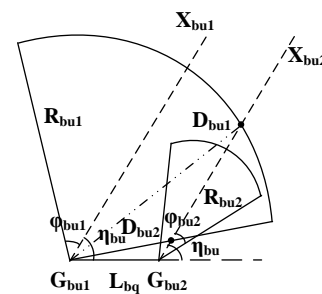


FIG. 4 SITUATION OF POINT DEFENSE SHIP-TO-AIR MISSILE SYSTEM BEING PROTECTED BY AREA DEFENSE SHIP-TO-AIR MISSILE SYSTEM

When η_{bu} Value is Known

At this time, the growth times of the firing frequency of the point defense missile system for the target is converted to distance representation, and the corresponding equation is defined by

$$|D_{bu1}D_{bu2}| = W_{bu}R_{bu2} \quad (12)$$

1) Solution Method for $|D_{bu2}G_{bu2}|$

In triangle $G_{bu1}D_{bu2}G_{bu2}$, because

$$\frac{L_{bq}}{\sin \varphi_{bu1}} = \frac{|D_{bu2}G_{bu2}|}{\sin(\eta_{bu} - \varphi_{bu1})},$$

$|D_{bu2}G_{bu2}|$ can be calculated by

$$|D_{bu2}G_{bu2}| = \frac{L_{bq} \sin(\eta_{bu} - \varphi_{bu1})}{\sin \varphi_{bu1}} \quad (13)$$

2) Solution Method for $|D_{bu1}G_{bu2}|$

In triangle $G_{bu1}D_{bu1}G_{bu2}$, because

$$\begin{aligned} |G_{bu1}D_{bu1}|^2 &= \\ R_{bu1}^2 &= L_{bq}^2 + |D_{bu1}G_{bu2}|^2 - 2L_{bq}|D_{bu1}G_{bu2}|\cos(\pi - \eta_{bu}) \\ &= L_{bq}^2 + |D_{bu1}G_{bu2}|^2 + 2L_{bq}|D_{bu1}G_{bu2}|\cos \eta_{bu}, \end{aligned}$$

$|D_{bu1}G_{bu2}|$ can be transformed by

$$\begin{aligned} |D_{bu1}G_{bu2}| &= \frac{-2L_{bq} \cos \eta_{bu} \pm \sqrt{4L_{bq}^2 \cos^2 \eta_{bu} - 4L_{bq}^2 + 4R_{bu1}^2}}{2} \\ &= -L_{bq} \cos \eta_{bu} \pm \sqrt{R_{bu1}^2 - L_{bq}^2 \sin^2 \eta_{bu}} \quad (14) \end{aligned}$$

where only a positive value is the $|D_{bu1}G_{bu2}|$ value.

3) Solution Method for $|D_{bu1}D_{bu2}|$

When $|D_{bu1}G_{bu2}| > |D_{bu2}G_{bu2}|$, the $|D_{bu1}D_{bu2}|$ value can be obtained; otherwise, it can't. $|D_{bu1}D_{bu2}|$ can be calculated by

$$|D_{bu1}D_{bu2}| = |D_{bu1}G_{bu2}| - |D_{bu2}G_{bu2}| \quad (15)$$

4) Solution Method for Spacing

Different W_{bu} values can be obtained based on Eq. (12) when the η_{bu} , φ_{bu1} , R_{bu1} , R_{bu2} values are known and the L_{bq} value varied within the given range $[0, L_{bqmax}]$, which can obtain the W_{bu} value curve corresponding to L_{bq} value. On the contrary, according to the curve, L_{bq} value corresponding to certain W_{bu} value can be determined.

When η_{bu} Value is Unknown

At this time, when η_{bu} value is varied within the given

range $[0^\circ, 180^\circ]$, L_{bq} value corresponding to W_{bu} value can be acquired. Afterwards, the maximum value of L_{bq} value (let L_{bqmax2}) can be taken as the final L_{bq} value.

Conclusions

During ship-to-air missile air defense operation, the commander usually confront some situations, such as two adjacent warships detected by the azimuth searching of anti-ship missile homing radar at the same time, mutual protection of two ship-to-air missile systems aboard the two adjacent warships, point defense ship-to-air missile system protected by area defense ship-to-air missile system. This paper has established corresponding spacing configuration engineering models of the two adjacent warships for ship-to-air missile defense, which can determine the spacing configuration in real-time to improve the missile system operation effectiveness.

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